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13. ABSTRACT *(Maximum 200 Words)*

The research performed under this grant dealt with the modeling of optical pulses propagating in arrays of nonlinear fibers. In this work, it is shown for the first time that a dynamics of self-localization happens. Here, pulses distributed along the array at input, coallesce into a single, intense and shorter pulse. It is then proposed to use this device as a pulse compressor. A second application studied, was that of switching accross the array. It is expected that in the near future, all optical switches will avoid existing bottleneck problems in data transmission, due to slow electronics. As a consequence of these studies, we proposed and studied novel switching mechanisms in fiber arrays. We demonstrate numerically and analytically conditions where an input pulse is switched to a prescribed output port.

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Final Technical Report of the RIP project "Mathematical modeling of novel optical fiber devices"

Grant: F49620-94-1-0007
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December, 1997

I. INTRODUCTION

The year 1996-97 marked the last year of this project. Overall, major progress in the understanding of the dynamics of pulses propagating in optical waveguides and fiber arrays was accomplished. Our group has played a central role in the modeling of these devices [1-5, 8-10, 12-14], which will play a major role in future all optical systems. Quoting a recent report in *Optics and Photonics News* (Feb. 98, p.28): *Optical switches, for years the domain of theoretical papers and hero experiments at the engineering conferences, are about to break through into commercial reality.* Indeed, recent experiments on waveguide arrays by S. Aitchinson's group at Glasgow and G. Setegeman's group at CREOL, University of Central Florida clearly indicate that novel and efficient all optical switching will soon be possible . We expect our research will prove to be a useful guideline for experiments in the near future.

Modeling of pulses propagating in nonlinear optical fiber gratings, has also been an area of research done by the PI under the support of the AFOSR [11]. Here, a major theoretical discovery was that of the existence of grating solitons, found the PI and S. Wabnitz in 1989. Only recently (1996), experimental work at Bell-Labs/Lucent Technologies has proved their realization. The relevance of this experimental discovery is evident by the recognition to the young experimentalist involved in the project, Dr. Benjamin Eggleton, who has been awarded the prestigious **OSA Adolph Lomb Medal** in 1998 for this work. To date, there is an ongoing collaboration between the PI of this project (Aceves) and the Bell-Labs group, to further investigate the pulse dynamics in fiber gratings. In particular, we are currently investigating modulational instabilities [16] and pulse collisions in fiber gratings.

Another area in nonlinear optics, where mathematical modeling has played a major role is that of pulse propagation in optical fibers. The PI has done research both for short pulse dynamics, where higher order corrections to the basic Nonlinear Schroedinger Equation model are necessary [6], as well as all optical long distance communications. Here, in a recent publication, the important effect of fast jitter in pulses, relevant to Wavelength Division Multiplexing (WDM) soliton communication systems with dispersion management was analyzed [16]. The PI continues working on this very active field.

II. HUMAN RESOURCES

A major accomplishment of this project has been in providing a forum for the formation of young scientists. Here is a list of people involved in the project and their current status:

- Prof. Costantino De Angelis: He was a postdoctoral fellow sponsored by this project and is currently a Professor at the Dipartimento di Elettronica ed Informatica, Universita di Padova in Italy.

- Prof. Gregory G. Luther: He was a postdoctoral fellow sponsored by this project. After his tenure here, we was a NSF Industrial Postdoctoral fellow, spending time at the University of Notre Dame, Caltech and at Hewlett Packard Research Institute in Bristol, England. Prof. Luther is currently an Assistant Professor at the Department of Engineering Sciences and Applied Mathematics, Northwestern University.

- Prof. Gustavo Cruz-Pacheco: He was a postdoctoral fellow sponsored by this project and is currently a Research Professor at the Instituto de Matematicas Aplicadas y Sistemas, Universidad de Mexico in Mexico City.

- Dr. Marco Santagiustina: He was a postdoctoral fellow sponsored by this project and is currently a Postdoctoral fellow at the Physics Department, Universidad Illes Balears in Mallorca, Spain.

- Dr. Barbara Costantini: She was a one year visiting research student. Her work here was part of her PhD project which she completed in 1996. She is currently a Research Associate at the Dipartimento di Elettronica ed Informatica, Universita di Padova in Italy

- Dr. Ma Concepcion Santos: She was a six month visiting research student. Her work here was part of her PhD project, which she finished this past December. She has a Faculty position at the Department of Universitat Politecnica de Catalunya in Spain.

- Dr. Anjan Biswas, a graduate student who did his PhD research under the guidance of the PI, defended his thesis this November. He also presented his work on the application of multiple scale methods to perturbed Nonlinear Schroedinger Equations relevant to nonlinear Optics, in the recent Southwest regional workshop conference at the University of North Texas.

  Dr. Biswas has accepted an Tenure-track position at "Valley City State University" in North Dakota.

- Mr. Paul Bennett: He is currently working on his PhD under the direction of the PI. Mr. Bennett has done summer research work with the

V. Kovanis and A. Gavrielides of the Nonlinear Optics group at Phillips Laboratory, Kirtland AFB in Albuquerque. He currently holds a Research Assistanship and is doing work for the Air Force High Performance Computing Center.

The PI recognizes and acknowledges the interaction he has had over the years with the Nonlinear Optics group at the former Phillips Laboratory, Kirtland AFB in Albuquerque NM; in particular with Drs. C. Clayton, A. Gavrielides and V. Kovanis. Although no specific joint work has been published, we had shared numerous ideas. This grant also supported a summer visit to the Lab. by Prof. Thomas Erneux, who is a regular visitor of Dr. Clayton's group.

Most recent publications which give acknowledgement to this grant follows:

a. "Coexisting periodic attractors in injection-locked diode lasers", A. Gavrielides, V. Kovanis, P. M. Varangis, T. Erneux and G. Lythe, Quantum Semiclassical Opt. **9**, 785-796 (1997).

b "Unfolding of the period two bifurcation in a fiber laser pumped with two modulation tones", T. C. Newell, A. Gavrielides, V. Kovanis, D. Sukow, T. Erneux and S. A. Glasgow, to appear Physical Review E December 1997.

c "Analytical stability boundaries for a semiconductor laser subject to optical injection ", A. Gavrielides, V. Kovanis, T. Erneux, Optics Communications **136**, 253-256 (1997)

The overall research supported by this project has been well recognized both in the Optics and the Applied Mathematics as well. This is evident from the more than 10 invited presentations in national and international workshops and numerous papers and posters presented in meetings organized by the Optical Society of America as well as about 10 University seminars and colloquia. Furthermore, the PI was a co-organizer of a minisymposium at the SIAM conference on Dynamical Systems in 1995; he is in the Scientific Advisory Committee of the Southwest regional conference in Dynamical Systems and he is in the program committee of the OSA workshop entitled *"Novel solitons and Nonlinear Periodic Structures"* to be held in Victoria BC, on March 1998. It should be pointed out that the research carried out under this project is consistent with some of the topics considered in the work-

shop (namely : optical solitons in fibers; gap and grating solitons; all optical switching in periodic structures and novel experimental geometries, materials and processes). These have been recognized as areas of prominence on future research in Nonlinear Optics. The PI also co-authored an invited paper for the first issue of the journal *Optical Fiber Technology* [7], dealing with an overview of the theoretical techniques relevant for the control of optical soliton interactions.

The closing of this project was highlighted by a very successful workshop sponsored both by this grant and by Brown University. This workshop entitled *"Pulse and Beam propagation in nonlinear optical systems"* (see 1997 Report for details), brought mostly young scientists actively involved in the general research area defined by the title. An important outcome was to delineate relevant problems to address in the future. The PI continues an active collaboration with some participants of the workshop.

III. MAJOR TECHNICAL ACCOMPLISHMENTS

Highlights of the results obtained in this project are summarized below. Some details can be found in the references and of the yearly reports as well, which appear here as Appendices.

1. Nonlinear optical waveguide and fiber arrays

- First theoretical demonstration of three distinct regimes characterizing the nature of stable localized modes in waveguide arrays [3]
- First detailed analysis of steering and interaction of localized modes in waveguide arrays [12].
- First thorough study on fiber arrays as means of compressing, steering and switching pulses due to the combined effect of temporal dispersion, nonlinearity and discrete nearest neighbor coupling [2, 5, 8-10, 13, 14]. These studies suggest future switches and multi-processors can be built based on these models. Nowdays, high dispersion can be achieved in fiber gratings and intense pulse sources are available. It is then expected that all the mechanisms studied in these models, as well as the effects predicted, have been or will be demonstrated in recent and future experiments. The PI continues communication with different experimental groups in the hope that some of our main propositions are followed.

Actual devices built around these principles need higher nonlinear materials (to avoid the cost of intense sources), where gratings can be "written" and coupling achieved in distances of a few centimeters.

This has been the central component of the project and detailed progress can be found in all yearly reports and references as well.

• Other switching mechanisms were studied for planar and coupled slab waveguides [1,6]. An important contribution on these works, was that the analysis was done beyond the traditional mode expansion approach.

• Work was done to study the Beam Steering and Routing in Quadratic Nonlinear Media (see 1997 report, or the paper *Beam Steering and Routing in Quadratic Nonlinear Media*, Technical Digest of the 1997 Quantum Electronics and Laser Science Conference, **QELS'97**, p. 171).

Here, we show how the spatial phase modulation of weak second-harmonic signals controls the overall direction of propagation of spatial solitons in quadratic nonlinear media. We investigate numerically such a process and suggest its applications to all-optical beam routing

2. Pulse dynamics in fiber gratings

• Modulational instabilities (MI) and pulse break-up were theoretically studied, with the results compared with experiments [16]. A simple model based on the Nonlinear Schroedinger Equation proved to be useful for frequencies close and outside the forbidden gap, defined by the linear dispersion relation. This was done in collaboration with Eggleton and Slusher (Bell Labs./Lucent Technologies); Prof. Martijn deSterke (University of Sidney, Australia) and Prof. John Sipe (University of Toronto, Canada). De Sterke is now studying MI beyond this model, using the governing coupled mode equations and extending previous work of Aceves and Wabnitz.

3. Soliton dynamics in long communication systems

• First theoretical prediction of a deterministic fast jitter occurring in pulses propagating in WDM for long communication systems, using dispersion compensation [15].

• A new collaboration was initiated by the PI with Prof. Chris Jones and Dr. Vadim Zharnitsky (Brown University) and Dr. Sergei Turitsyn (University of Duesseldorf, Germany) in the study of long distance pulse dynamics in dispersion managed systems. Here we derived the long (averaged) dynamics of pulses in such systems; more concretely looking at the case where locally the system is highly dispersive. A paper entitled *"Average dynamics of the optical soliton in communication lines with dispersion management: Analytical results"*, has been recently submitted to Physical Review Letters.

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Other publications with acknowledgement to this grant:

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